to the filtering results. In particular, for both state and signal process estimation, the same quantities are required for computing optimal predictors and their performance as are required for computing optimal filters and their performance.

ACKNOWLEDGMENT

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Computer Simulation Models of Human Behavior: A History of an Intellectual Technology

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Abstract—**The history of the growth and development of the technology of computer simulation is reflected in an analysis of 2034 sight-read and classified simulation studies of human behavior published before 1971. The limiting goal of the work was an exhaustive bibliography of these simulation studies. The empirical studies referenced are classified into four major model categories for analysis: 1) individuals, 2) individuals who interact, 3) individuals who aggregate, and 4) individuals who aggregate and interact. Each of these studies is also classified into one of eight types, according to the empirical relationship between the model and reality. Additional classifications are employed to describe methodological studies. The analysis includes estimates of the completeness of the bibliography and of the reliability of the classification scheme, as well as the distributions of studies by category and type.**

PURPOSES

THIS IS a paper on a multipurpose bibliographic study. One purpose was to more precisely define a body of scientific literature in which the authors shared a strong interest. A second purpose was to retrieve and classify this literature according to predetermined, explicit decision rules. A third was to gather the necessary data base for analytic study of the growth and development of one intellectual technology, namely, computer simulation models of human behavior.

Computer simulation is a technological invention in much the same sense as the Bessemer furnace. While simulation is an ambiguous concept which is used in a more abstract intellectual world, nonetheless, such concepts govern much behavior. Yet we know of no studies of the adoption and diffusion of intellectual technologies like simulation comparable to studies of physical technologies like the Bessemer furnace.

The major source of data on the results of efforts to develop and use an intellectual technology like simulation is the literature. Hence the first requirement of an empirical study of the growth and development of simulation is an exhaustive bibliography. An added nonincidental result is the value of such a classified bibliography to simulation users.

SCOPE AND CONTENT OF BIBLIOGRAPHY

The document population sought was the set of all English-language reports of simulation studies concerned with the description of human behavior, or with the development of computer models as one technology for making descriptive statements about human behavior.

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Many well-known studies are not included in this bibliography. It is highly unlikely that such studies were left out because of ignorance. Nearly five sixths of the 12 000 articles and documents we examined during a year of intensive effort were intentionally omitted. One reason for omission was the unavailability of a study. Our bibliography includes only the articles and documents which we could obtain. Roughly one fourth of the citations in other articles and bibliographies were found to be erroneous, and approximately one half of one percent of the citations either could be proven never to have existed or could not be proved to exist in 1969. Since entries in the bibliographies are limited to works actually retrieved and read by us, errors in the citations included are limited to errors of transcription or typography. The reader can thus assume that a document physically existed in 1969 which corresponds to each entry in the bibliography. The only exception is that some Ph.D. dissertations have been cited and classified on the basis of abstracts printed in *Dissertation Abstracts.*[1]

The major reason for omitting studies, however, was because they did not discuss computer simulation of human behavior by our definition of the topic. We defined computer simulation as a model or representation entirely realized through a mechanical system. The system did not have to be called a "computer." Obviously the systems conceived and constructed before 1940 were not called computers. But the system did have to be mechanically complete, and the author did have to characterize it as an analog of a real-world process. Thus simulation games and man–machine simulations were omitted because portions of the models were not mechanical.[2] Hand simulations and mathematical models were omitted unless the publication explicitly anticipated a machine model. Some computer programs were omitted because their authors viewed them as data-processing procedures which did not represent reality. Studies of artificial intelligence are included when intelligence was defined by comparison to human behavior or when the system's components were modeled on human processes.[3] Simulations of physical systems such as nuclear reactions were omitted. Also excluded were simulations of partly human systems where the human components were left undescribed.[4] Mixed cases are included and are classified according to the portions of the model that describe human behavior. For instance, several studies of factories and their markets treat the market portion as human behavior but the factory portion as machines. These studies are classified on the basis of their market components only.

The human being is himself a physical system. Thus a decision which immediately posed itself was the necessity of defining a boundary between relevant and irrelevant human behavior. We defined relevant human behaviors to be those displaying at least one of four properties: 1) learning, 2) perceptual gestalt, 3) choice, or 4) social effects.

This definition excluded physiologically oriented studies of, say, the human circulatory system. Most studies of aural perception and human-operator studies were also excluded because they examined the human as a time-invariant mechanical system. Included are those neural models which represent learning. And most studies of visual perception are included because the model-builders in this area have emphasized learning and pattern recognition.[5]

We also excluded publications solely devoted to the subject of simulation hardware and software. Many publications discussed the effectiveness of alternative analog hardware configurations, and many discussed the effectiveness of alternative programming languages for digital machines. The only discussions of hardware and software included are those which examined substantive modeling tasks, and their bibliographic classifications are based on how such substantive problems were treated.[6]

BIBLIOGRAPHIC CLASSIFICATION SCHEME

Each entry in the bibliography has been assigned a two-character classification code. In each case this assignment is based on our interpretation of the relevance of the piece to computer simulation of human behavior. The first character in the code describes the type of empiricism used in the particular study. The second character describes the study's general subject category.

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[1] Dissertations were virtually the only documents included and classified on the basis of abstracts because in the case of dissertations one can be sure that a reference document actually exists. Abstracts themselves were excluded from the bibliography unless they were so long as to comprise short articles. Also excluded as unavailable were a few documents which came into our hands fortuitously even though they bore the designations "secret" or "confidential." Our rule was that documents should be examined if they were available to the general public in 1969, whereas documents which had restricted circulations in 1969 should be ignored.

[2] A few man–machine simulations are included on the grounds that a subset of the system was a self-complete computer simulation. In these cases the bibliographic classification describes only the subset. An example is I. D. Pool and A. R. Kessler, "The Kaiser, the Tsar, and the computer: information processing in a crisis," 1965.

[3] For example, the bibliography includes O. G. Selfridge, "Pattern recognition and learning," 1956, but it does not include O. G. Selfridge, "Pandemonium: a paradigm for learning," 1959. Three other publications excluded as being concerned with artificial intelligence are: L. A. Hiller, Jr. and L. M. Isaacson, *Experimental Music*, 1959; N. J. Nilsson, *Learning Machines*, 1965; and M. D. Seversky, "Retail forecasting," 1966.

[4] Typical publications excluded as not being concerned with human behavior are: M. S. Bartlett, "Measles periodicity and community size," 1957; D. A. D'Esopo, H. L. Dixon, and B. Lefkowitz, "A model for simulating an air-transportation system," 1960; F. K. Tan and J. M. Burling, "Manufacturing planning using simulation," 1967; and W. O. Turner, "Traffic simulation," 1963.

[5] Studies of "animal" or "mammalian" behaviors are included when the authors included humans as a subset, and excluded when it appeared that the authors meant animal-as-opposed-to-human behaviors. Excluded on this basis, for instance, was E. C. Tolman, "Prediction of vicarious trial and error by means of the schematic sowbug," 1939. Example publications excluded because they were physiologically oriented are: E. R. Caianiello, A. deLuca, and L. M. Ricciardi, "Reverberations and control of neural nets," 1967; R. L. Cosgriff and G. E. Briggs, *Accomplishments in Human Operator Simulation*, 1960; D. B. Fry and P. Denes, "The solution of some fundamental problems in mechanical speech recognition," 1958; and R. Wyman, "A nerve net simulation," 1962.

[6] Typical hardware–software exclusions are: T. H. Barker, *A Computer Program for Simulation of Perceptrons and Similar Neural Networks: Users Manual*, 1966; D. Gross and J. Ray, "A general purpose forecast simulator," 1965; and D. Longley, "An analogue computer application in operations research," 1964. However, the bibliography includes H. S. Krasnow, "Simulation languages: facilities for experimentation," 1969, because of its substantive relevance.

TABLE I

CODES IDENTIFYING STUDY TYPES

	The use made of real-world data and the kind of measurement employed			Percentage of publications assigned this code	
The content of the publication	Data used to demonstrate the realism of a model's formulation or its inputs -- prior use of data	Data used to demonstrate the realism of a model's outputs -- posterior use of data	Code symbol	Published between 1958 and 1966	Published before 1969
Description of a working model; that is, the hardware or program was operative	Quantitative measurement	Quantitative measurement	1	3.8	4.0
	Quantitative measurement	Qualitative or negligible measurement	2	5.0	5.4
	Qualitative or negligible measurement	Quantitative measurement	3	7.6	6.8
	Qualitative measurement	Qualitative measurement	4	2.9	2.9
	Qualitative measurement	Negligible measurement	5	10.6	9.9
	Negligible measurement	Qualitative measurement	6	3.4	3.9
	Negligible measurement	Negligible measurement	7	12.6	12.5
Description of a proposed or inoperative model	Not relevant	Not relevant	8	7.8	6.8
Methodological discussion which does not present a working model	None	None	M	46.2	47.8

Type of empiricism refers to the relation between a model and real-world data. The codes were designed to discover whether simulation studies have become more empirical and systematic over time. The codes assigned to uncover such evolutionary patterns characterize each publication as: a methodological discussion, a description of a model which had not yet been built, or a description of a working model. Descriptions of working models were further classified according to how systematic and precise were the comparisons between the model and the real world, and according to whether real-world data were used to document the model's structure, the model's output, or both. These code symbols are given in Table I together with the percentages of publications assigned each symbol. Percentages are given both for all documents published before 1969 and for documents published between 1958 and 1966, the period for which the bibliography should be most complete. The 1958 to 1966 period includes 1256 publications, about 65 percent of the bibliography.

The numeric codes are independent of the properties of a model itself, properties like realism, complexity, completeness, innovativeness, or sophistication. The codes are not intended to measure a publication's goodness. We conjecture that social acceptance of descriptive simulation models has been most influenced by studies that demonstrate validity by relatively rigorous and impersonal standards which permit replicability. Thus we classified studies according to the ways correspondence between the model and reality was measured.

Each study was evaluated on two dimensions: 1) its use of data to insure that inputs to the model were realistic or to insure that the structure of the model was realistic or both; and 2) its use of data to demonstrate that the model behaved realistically. Each of these two dimensions could take one of three values: quantitative (systematic) measurement, qualitative measurement, or negligible measurement. The norm for quantitative measurement was a numerical table of any sort or analysis of qualitative data when the analysis was detailed and systematic, such as line-by-line analysis of a problem-solving protocol. The norm for qualitative measurement was a list of properties such as "learning," "oscillation," or "stability." The norms for negligible measurement were either an unsubstantiated claim that the model was realistic or discussion of the model's properties in ambiguous and abstract terms, like "intelligence." The adoption of a mathematical model on the grounds of its computational convenience was classified as an instance of negligible measurement, as was the description of a model's behaviors unaccompanied by statements that the real-world system produced similar behavior. In all cases we avoided introducing our own beliefs as readers on the prior–posterior data issue and tried to adhere to the statements of the original authors. Whether real-world data were used in a prior or posterior manner was often ambiguous. In these cases we tried to be governed by the model-builder's intent rather than substitute our own criteria. Toward this end, and for evidence of author intent in other aspects of the study, we sought out clues such as footnotes where computation center assistance was acknowledged, computation methods were described, or data sources cited.

Except for the prior–posterior issue, our own criteria dominated the classification of publications. Many authors may disagree with our classification of their work. For

TABLE II

Codes Identifying Subject Categories

			Percentage of publications assigned this code	
The object of study	Criteria	Code symbol	Published between 1958 and 1966	Published before 1969
Individuals	Modeled people who could probably be identified by name	A	30.5	30.8
Individuals who interact	Identifiable people or hypothetical "average" people who forecast, react to, or communicate with others	B	4.8	4.7
Individuals who aggregate	People who are added together and do not interact	C	25.0	23.2
Individuals who aggregate and interact	People who are added together and who interact with one another either before or after being added	D	23.7	23.5
Simulation methodology -- type M	Emphasis on systematic, formal methods such as statistical techniques	S	6.1	7.7
Simulation methodology -- type M	Too general to assign to categories A, B, C, D, or S	G	9.9	10.1

instance, nearly half the entries in the bibliography are labeled M. This high percentage would be much higher had study–author preferences dominated. We minimized the number of M publications by classifying on the basis of a model whenever a model was described, even when the model was given as an example rather than the main thrust of the work. We adopted this rule because we believe working models are the major stimulus to the adoption of new research methods.

Altogether, 311 studies were classified as instances of quantitative measurement (types 1, 2, and 3) and 320 studies were classified as instances of qualitative measurement (types 4, 5, and 6). Another 240 studies involved only negligible measurements (type 7). Thus 28 percent of the studies listed in the bibliography reflect the belief that empirical measurement is not necessary. The remaining 72 percent are nearly equally divided between the position on balance that the return from the use of rigorous measurements exceeds the cost and vice versa.

Subject categories are specified by a second alphabetic character which follows the first, type of empiricism, character. Category A denotes studies of individual human beings. Category B denotes studies of individual people who interact with other individual people. Category C denotes studies of aggregated individuals where the behavioral measures were summed or averaged across many people, but the model did not show interaction between people. Category D denotes studies of aggregates which interact or studies of aggregated interactions or both. Thus 3B denotes a type 3 study of individuals who interact, and 1A denotes a type 1 study of individual behavior.

Alternative classification schemes for the bibliography were considered and laid aside. More specifically, we debated organizing the bibliography according to academic disciplines such as psychology, sociology, or economics; according to problem areas such as voting behavior, business decision-making, or traffic engineering; or according to simulation classes like queuing models, simultaneous difference equations, or massive data problems. The first two schemes would place similar models in different categories and would create artificial categories different in name only. The third scheme lumps together studies with different objectives and implies that each study used the kind of formulation approach which it should have used.

Seeking to avoid these drawbacks, we invented a classification scheme having some properties of a disciplinary or problem area scheme, but which involves only four broad categories of simulation models, as stated in the preceding. These categories reflect the way the model-builder defined his problem, but this intent tends to be associated with the kind of model adopted. The aggregative categories C and D make more extensive use of probability distributions and stochastic formulations than the nonaggregative A and B categories. The interactive categories B and D use more forecasting and feedback functions than the noninteractive A and C categories.

There is also correspondence between model categories and the substantive problems studied. For instance, nearly all studies by psychologists fall into category C because of the disciplinary tradition that the proper object for study is a group average rather than models of individual human beings. Similarly most studies of large economic systems fall into category D because individual behavior is grouped and aggregated. Then these grouped decisions are treated as simultaneous functions of one other.

Two other bibliographic subject categories, MS and MG, include methodological studies that extend to contexts beyond human-behavior simulation. The rule adopted was

TABLE III

DISTRIBUTIONS OF STUDY TYPES WITHIN EACH SUBJECT CATEGORY

	Category A		Category B		Category C		Category D		Categories S and G		Comparisons across categories of the percentages for each study type*			
Study types	1958-1966	To 1969	1958-1966	To 1969	1958-1966	To 1969	1958-1966	To 1969	1958-1966	To 1969	Very low	Low	High	Very high
Type 1	2.9	2.9	5.0	5.5	6.4	5.4	4.7	6.6				A,B,D	C	
Type 2	.8	1.2	10.0	9.9	8.9	9.4	8.7	10.2			A		B,C	D
Type 3	3.9	3.0	16.7	15.4	18.8	18.7	4.0	3.5			A,D			B,C
Subtotal for quantitative measurement	7.6	7.1	31.7	30.8	34.1	33.5	17.4	20.4			A	D	B	C
Type 4	3.9	3.7	3.3	4.4	2.9	3.4	3.7	3.3			C	B,D		A
Type 5	8.1	6.9	16.7	14.3	15.9	16.2	14.1	14.2				A,B	C,D	
Type 6	4.2	6.1	5.0	3.3	6.1	5.6	1.7	2.2			D	B	C	A
Type 7	11.2	10.3	20.0	25.3	11.5	14.2	22.5	20.6			C	B	A	D
Subtotal for qualitative or negligible measurement	27.4	27.1	45.0	47.3	36.3	39.3	41.9	40.3				B,C	A.D	
Type 8	9.1	7.6	10.0	12.1	6.1	4.9	12.8	11.7			C	B	D	A
Type MX where X is A,B,C,or D	55.9	58.2	13.3	9.9	23.6	22.2	27.9	27.7			B	C,D		A
Type MS									38.3	43.4				
Type MG									61.7	56.6				
Subtotal for methodological discussions	65.0	65.8	23.3	22.0	29.6	27.2	40.6	39.4			B	C,D		A

*Comparisons are based on the 1958-1966 data with MX publications excluded, except, of course, from comparisons involving type M. The judgments denote: Very low < .7P < Low < P < High < 1.3P < Very High , where P is the mean percentage across the four categories.

that a publication on simulation methods should be included unless it explicitly identified a context other than human behavior. All other bibliographic categories are restricted to descriptive models of human behavior, and most methodological studies are coded MA, MB, MC, or MD because they were assigned to subject categories whenever a subject emphasis could be identified. All discussions of "intelligent machines" and of simulation of thought were classified MA. All discussions of Monte Carlo were classified MC. And all discussions of systems simulation and macroeconomic simulation were classified MD. Those discussions too diffuse to assign to a subject category were coded MG. Other methodological publications which emphasized the development of a highly systematic and formal simulation technology were coded MS. Table II summarizes the subject categories and gives the percentages of publications assigned to each, again both for all documents published before 1969 and for documents published between 1958 and 1966.

PUBLICATION FREQUENCY BY STUDY TYPE AND SUBJECT CATEGORY

Adoption of this overall classification scheme resulted in the use of 38 codes in the bibliography. These codes include the MS and MG classifications plus the 36 combinations of (1, 2, 3, 4, 5, 6, 7, 8, M) with (A, B, C, D).

Table III shows how the publication frequencies of study types varied from one subject category to another and identifies the categories containing high and low percentages of each type. Type M studies were deleted from the distributions before the high–low judgments for types 1 to 8 were made.

The four categories form a similarity ordering—A, D, B, C—in which closer elements have larger correlations between their distributions. Category A includes a very high proportion of methodological discussions which reflect the popularity of debating whether machines can simulate thought. Subject category A also contains a surplus of proposed models and a deficiency of models based on systematically collected data. Category D contains a high proportion of unverified and weakly verified models. In practice we found almost no studies which were properly classifiable in subject category B—individuals who interact with one another—as it was initially defined. Thus category B was enlarged to include portions of categories A, C, and D. Now category B includes studies of single individuals (category A) or studies of "average" individuals (categories C and D) in which the model incorporated a) forecasts of another's behaviors, b) messages received from another, or c) explicit responses to another's behavior. As a result, B is the category most like the average of the four. The low frequency of methodological publications in category B could also well be an artifact of our classification rules because types MA, MC, and MD were each associated with broad topics of discussion, whereas MB was not. Category C contains very low percentages of proposed models, models based on negligible measurements, and models based on balanced prior and posterior qualitative measurements.

TABLE IV

PERCENTAGE YIELDS OF TWO SHORT BIBLIOGRAPHIES VERSUS PRESENT BIBLIOGRAPHY

	Werner-Werner, 326 references, compiled during 1968*	Dutton-Bailey, 326 references, compiled during late 1967 and early 1968*
before 1956	4.8	4.7
1956	8.8	4.3
1957	14.4	5.6
1958	34.4	10.0
1959	14.3	14.3
1960	20.0	18.8
1961	15.0	20.3
1962	23.7	28.7
1963	19.3	21.9
1964	18.8	25.0
1965	31.3	23.2
1966	13.2	19.4
1967	13.8	18.2
1968	10.9	10.3

*Figures shown are percentage for each short bibliography of the present long one.

COMPLETENESS

Exhaustive bibliographic search of a sizeable literature is no mean feat. The difficulty of achieving this goal probably explains the relative absence of intellectual technology studies. When the document population is unknown, random sampling is impossible. Thus search must be based on heuristic rules. Such rules are inherently biased, but the bias can only be removed by expanded coverage of the document population: hence a dilemma.

In a year and a half of study we examined more than 12 000 articles and documents. Our efforts uncovered 1921 relevant items published before the year 1969 and 2034 items including partial coverage of the years 1969 and 1970. These are estimated to include only three fourths of what has been written, but because our heuristics for high-yield search were depleted, we terminated the study. Each additional item was requiring increasingly more time to locate, and the estimate of time for complete coverage was so very long that 100 percent coverage would have in effect meant a never-ending search.

While our bibliography contains less than 100 percent of the computer simulation literature sought, we are sure it is much more complete than any other published thus far. We examined the documents cited in all the other bibliographies we found. We also sought to retrieve for examination all references contained in every simulation study which we had obtained. Moreover, when we found a journal which contained several simulation studies, we exhaustively searched every issue for additional publications on simulation.

An attempt was made to test and measure the completeness of our bibliography's coverage. This test was based on a bibliography by Werner and Werner,[7] which we discovered when our search was nearly ended. Werner and Werner did not define a relevant document as we did,[8] but 326 of the publications cited are relevant or probably so by our standards. Of these 326 items, 266 had been discovered by our previous search and 60 were added to our search as a result of seeing their bibliography.[9] If their bibliography is a representative sample from the document population, our bibliography included 82 percent of the population before we saw Werner and Werner and includes 84 percent of the population now.[10] Werner and Werner's bibliography is only one sixth as large as ours and therefore less likely to be representative. Since we used some of the same search methods as Werner and Werner, the duplication rate

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[7] R. Werner and J. T. Werner, *Bibliography of Simulations: Social Systems and Education*, 1969.

[8] Werner and Werner include progress reports on research grants, short abstracts of speeches, news reports, a financial report, documents written in languages other than English, Ph.D. dissertations which are neither included in *Dissertation Abstracts* nor immediately available in other forms, and documents which are secret or confidential and are unavailable to the public. Also included is one item for which we searched extensively without being able to establish that a written form ever existed. We have excluded all of these as not falling within the document domain which interests us. Moreover, Werner and Werner do not restrict their bibliography to computer simulations of human behavior. They include games, man-machine simulations, hand simulations, mathematical models, uses of computers for data processing, studies of artificial intelligence, and simulations of physical systems.

[9] Of the Werner and Werner citations, 265 were in our bibliography before we saw theirs, 50 were added to our bibliography on Werner and Werner's lead, and 17 may be relevant but we have not thus far been able to acquire them. On the basis of authors and titles, 6 of the 17 are probably not relevant; 10 are probably relevant and were brought to our attention by Werner and Werner; and one is probably relevant but already we had been trying to obtain it.

[10] These percentages apply only to pre-1969 items. Our coverage of 1969 and 1970 items is erratic and low.

TABLE V

CLASSIFICATION RELIABILITIES

Estimated frequencies of a second classification that is:	Percentages considering only the subject category	Percentages considering only the model type	Percentages considering both the subject category and the model type
Exactly the same as the first	71	65	45
Different from the first but similar to it	22	21	39
Significantly different from the first	8	14	16
Totals	100	100	100

between the two bibliographies is almost surely higher than for two representative samples. Thus 84 percent is an optimistic estimate of our bibliography's coverage. Say half the 266 items included in both bibliographies would automatically be found in any broad-scope bibliography on simulation, then our bibliography now covers 71 percent of the document population. This 50 percent automaticity seems conservatively high considering the substantial differences in the criteria for inclusion across the two bibliographies. Thus we present a bibliography which contains between 71 and 84 percent of the literature on computer simulation of human behavior before 1969.

It can be expected that the bibliography is biased in its coverage with respect to time. It undoubtedly provides greatest coverage of publications from the late 1950's to early 1960's. Early publications are less easily found because they are rare and because the terms computer and simulation were not used. Thus relevant studies were indexed by other criteria. Very recent publications are missed because of the lag introduced by library acquisition between publication and visibility and because recent work is not yet cited.

If it is so that the present bibliography understates very old and very new publications, then, smaller bibliographies should be even more biased. Two smaller bibliographies are available for comparison: that by Werner and Werner compiled about one year before ours was, and an ancestor of our bibliography by J. M. Dutton and H. E. Bailey compiled about 18 months earlier than ours. Both bibliographies contain 326 references, and both show 1965 as the peak publication year, whereas our later bibliography shows 1966 as the peak year. The data given in Table IV show the expected low yields early and late for the two short bibliographies relative to our later long one.

RELIABILITY

The use of an explicit multicategory classification system involves a question of reliability. Implicitly such a scheme argues that a piece is uniquely identifiable in one category and only one. But a study may exhibit characteristics belonging to more than one category.

To permit estimates of reliability, cases were recorded where a publication was classified twice during the literature search. Forty-four such cases occurred and were used to compute the estimates of the classification scheme's overall reliabilities shown in Table V.

The estimates of reliability in Table V are pessimistic because the main reason for examining publications twice was that we found reasons to suspect that the earlier classification was wrong.[11] The heading "different from the first but similar to it" means a) the two classifications do not differ both in subject category and in model type, and b) the differences occur in only one dimension of the category or type space, such as aggregation or interaction, prior or posterior.

CHRONOLOGICAL ORGANIZATION

The bibliography is organized into lists for each of the six separate categories as follows.

A Studies of individual human beings.
B Studies of individuals who interact.
C Studies of aggregated individuals.
D Studies of aggregation and interaction.
MS Systematic and formal methodological discussions.
MG Diffuse methodological discussions.

Within each of these six categories, studies are listed in chronological order by year. Within each year, studies are listed in order of their type (1, 2, 3, 4, 5, 6, 7, 8, MX). Within each type, the studies are listed alphabetically by author.

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[11] The usual procedure of replicating a randomly chosen subset of the classifications has not been used because it would produce optimistic estimates of the reliabilities—probably very near 100 percent. The classifier's memory produces a fundamentally ineradicable bias in second readings.

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A Pattern Recognizing Study of Palm Reading

Abstract—**Palm reading is studied from the viewpoints of pattern recognition, heuristics, and learning. Two kinds of mapping in palm reading are extracted, these being a tree-decision type and a polynomial type. In contrast to the fairly simple form of mapping, the palm input is relatively complicated but well chosen. The generalization and speciality of palm reading, variations of palm lines, examples of palmistry judgment, and the roles of heuristics and learning in palm reading are mainly discussed.**

I. Introduction

The purpose of this correspondence is to clarify the decision mechanism of palm reading (palmistry, or chiromancy) from the viewpoints of pattern recognition, learning, and heuristics. Palm reading can be considered as a special problem in what is widely defined as pattern recognition. The study of this problem seems very important but is difficult and therefore similar to the problems of reading handwritten characters and numerals, and of identifying human faces.

Generally, we can list the following three kinds of approaches to the study of the hand:

1) medico-legal study of fingerprints and palms[1] as a means of identification [1];
2) dermatoglyphical study of fingerprints, palms, and soles, which includes anthropology, medicine, genetics, and anatomy [2], [3];
3) occult study of hands (fingers and palms), as in palmistry or chiromancy [4]–[9], which requires knowledge in modern psychology, anatomy, and phylogeny [9].

This correspondence does not concern approaches 1) and 2) which have been studied in a scientific way, but concentrates on approach 3) which seems to have been studied spuriously only in an occult way. This correspondence will, however, consider *pattern recognizing* (instead of *occult*) approaches to the human decision-making mechanism of palm reading [4]–[9]. Such a study is made first here according to the author's knowledge. (This is a modified and developed version of [10].)

Palm lines might seem complicated at a glance. They are considered sometimes to be occult or to need a special master skill for their reading. It is found, however, as a main result of this correspondence,

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[1] As a means of identification, palm lines are better than fingerprints, but it is less practical (more difficult) to make good impressions.